Geologic Resource Evaluation Scoping Summary
Aztec Ruins National Monument, New Mexico

Geologic Resources Division
National Park Service
US Department of the Interior

Prepared by Katie KellerLynn
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Administered by the NPS Geologic Resources Division (GRD), the Geologic Resource Evaluation (GRE) Program provides each of 270 identified natural-area units in the National Park System with a geologic scoping meeting, a digital geologic map, and a geologic resource evaluation report. The purpose of scoping is to identify geologic mapping coverage and needs, distinctive geologic processes and features, resource management issues, and potential monitoring and research needs. Outcomes of this scoping process are a scoping summary (this report), a digital geologic map, and a geologic resource evaluation report. Participants at geologic scoping meetings evaluate the adequacy of existing geologic maps for resource management, discuss park-specific geologic management issues, and if possible tour the site with park staff and geologists knowledgeable about the park's geologic resources.

The National Park Service held a GRE scoping meeting for Aztec Ruins National Monument on February 13, 2007. Superintendent Dennis Carruth welcomed the participants. Tim Connors (GRD) facilitated the evaluation of map coverage, and Lisa Norby (GRD) led the discussion regarding geologic processes and features at the monument. Mary Gillam (San Juan College, New Mexico, and Fort Lewis College, Colorado) presented information about the geomorphology of the monument, in particular the alluvial terraces. Participants at the meeting included NPS staff from the monument and the Geologic Resources Division, and cooperators from the City of Farmington, Bureau of Land Management, New Mexico Bureau of Geology & Mineral Resources, U.S. Geological Survey, and Colorado State University (table 1). After discussions, participants toured the national monument, hiking to the vantage point of the highest terrace, which is commonly referred to as the "north mesa" (5,820 feet [1,774 m]). Stops included the West Ruin (fig. 1), which was built on an alluvial fan; a "house mound"—large pueblo of cobbles and adobe, including walls and middens—built outside the main ruins; the irrigation ditch; the sole bedrock outcrop at the monument (sandstone of the Nacimiento Formation); and one of three oil wells currently operating in the monument (see "Oil and Gas Development" section).

This scoping summary highlights the GRE scoping meeting for Aztec Ruins National Monument, including the geologic setting, the plan for providing a digital geologic map, a list of geologic resource management issues, a description of significant geologic features and processes, and a table of meeting participants.

Park and Geologic Setting

Aztec Ruins National Monument preserves an outstanding example of an ancestral Puebloan farming community, including a complex of public structures and ceremonial buildings (fig. 1). Aztec Indians never lived here; rather ancestral Puebloans inhabited this site for about two centuries (ca. AD 1100–1130). After various changes to boundaries since its proclamation in 1923, Aztec Ruins National Monument now encompasses 318 acres (129 ha) within the City of Aztec, New Mexico. As stated in the park brochure, "By the time building ceased in the late 1200s, the complex consisted of several great houses, tri-walled kivas, small residential pueblos, earthworks, roads, and great kivas. Far from being an uncontrolled urban sprawl, the formal layout of the settlement, purposeful landscape modifications, and the orientation and visual relationships among the buildings all indicate a grand design." Located between two major centers—Chaco Canyon to the south and Mesa Verde to the north—Aztec was one of the largest ancestral Puebloan settlements in the Southwest (Thybony, 1992).

The ancestral Puebloans took advantage of the perennial waters of the Animas River, which runs along the eastern boundary of the national monument. Many modern Puebloan people know this site as the "Place by Flowing Waters," though other names exist. The Animas River flows from the San Juan Mountains through the San Juan Basin, crossing varied rock types before joining the San Juan River near Farmington, New Mexico. The landscape through which the river travels is reflected in the variety of rock types and grain sizes in the alluvium deposited in the national monument (fig. 2). Much of this alluvial material, which ranges in size from cobbles and gravels to unconsolidated sand, was used in construction at Aztec Ruins. However, the distinctive "greenstone" bed of the Nacimiento Formation (Paleocene Epoch), decorative bands of which are incorporated into the ruins, was quarried outside of the monument at a site near Tucker Canyon, about 3 miles (5 km) from the monument.

Figure 1. West Ruin, Aztec Ruins National Monument, New Mexico. NPS photo/AZRU files

Aztec Ruins National Monument is located in the Animas River valley, which is significant as the former site of the largest glacier bordering the Colorado Plateau (Gillam, 1998). The Animas Glacier was one of several valley glaciers that issued from a small ice field in the San Juan Mountains. Aztec Ruins lies on outwash of this glacier, which may have been reworked during interglacial times. Middle and late Pleistocene glacial end moraines occur at Durango, Colorado, and river terraces of Holocene to late Miocene (?) age are preserved in places for 50 miles (80 km) from Durango south to Farmington (Gillam, 1998). Three groups of moraines, ranging in age from approximately 15,000 to 360,000 years old, are differentiated by increasing distance down valley, heights above river level, and later modification (e.g., soil development) (Gillam, 1998). Investigators have also identified roughly 34 existing terrace levels in the Animas valley between Durango and Farmington; three of these occur in Aztec Ruins National Monument. These flat alluvial surfaces step up in elevation from the modern floodplain (Holocene Epoch) to old, "stranded" floodplains as high as 2,165 feet (660 m) above the valley floor. In most places, younger alluvial fan deposits and eolian loess overlie the terrace alluvium. Gillam (1998) used the Lava Creek B ash (~640,000 years old) from a Yellowstone ash-fall event and regional correlations to estimate ages for each terrace level. Geologically speaking, terraces are significant because they record entire glacial-interglacial cycles and can be well preserved, though the oldest terraces in this area may be unrelated to glaciations. In contrast, end moraines record only the maximum or near-maximum extent of the glacier, and older ones are often destroyed during younger ice advances.

Changes in channel gradient, discharge, or sediment load can lead to a river channel incising (downcutting) into its floodplain. As a result, the former floodplain is abandoned and left as a relatively flat surface (terrace), which is separated from the new floodplain below. Terraces can form in the alluvial fill of river valleys or be cut into bedrock (i.e., strath terraces). The three terrace levels at Aztec Ruins are primarily strath terraces. From youngest to oldest the terraces at Aztec Ruins are t7u, t6a, and t5a (Mary Gillam, e-mail communication, March 6, 2007). Terrace level t7u consists of several individual terraces that were grouped for mapping purposes because they are very close in elevation and cannot be traced for long distances; in contrast, the remaining terraces near Aztec Ruins appear as single levels. At Aztec Ruins, t7u includes at least two benches with an average elevation of roughly 15–20 feet [<3–6 m] above the modern floodplain (Mary Gillam, e-mail communication, June 4, 2007). Terrace t6a is 100–110 feet (30–34 m) above the modern floodplain at Aztec Ruins, and terrace t5a lies 160–165 feet (49–50m) above the modern floodplain. Another level (t4e), occurring just west of the monument (Mary Gillam, e-mail communication, March 6, 2007), is about 305 feet (93 m) above the modern floodplain. These heights are for the tops of the gravelly alluvial deposits that underlie each terrace bench. Gravel thicknesses beneath these surfaces are likely around 8–25 feet (2.4–7.6 m). All of the terraces are overlain by additional but varying amounts of fan alluvium and loess.

The history of river incision around the San Juans is complicated by mid-Tertiary volcanism, which occurred episodically from 35 until 18 million years ago. Volcanic eruptions produced a thick volcaniclastic apron that probably covered the Aztec area (Smith et al., 2002). Investigators have suggested that this volcaniclastic deposit formerly extended into piedmont areas around the southwestern part of the range, possibly even to the state line (Cather et al., 2003; Cather, 2004). The ancestral Animas River was probably established after the Laramide Orogeny—a mountain-building event that began about 70 million years ago—perhaps as late as Miocene time. Therefore, downcutting of the Animas River valley began before glaciation, but probably after the end of mid-Tertiary volcanism in the San Juan Mountains; that is, between 18 and 3 million years ago. Regional relief also results in part from the earlier Laramide uplift. In the Animas River valley, continuing incision may be a result of isostatic compensation of landscape denudation, tectonically caused base-level fall, and headward erosion that followed stream captures that occurred farther downstream along the Colorado River. Short-term changes in the river's incision rate, caused by glacial-interglacial climatic cycles, account for the formation of terraces. Terrace ages and early river diversions suggest that incision has accelerated toward the present (Gillam, 1998).

Figure 2. Alluvium of the "North Mesa" at Aztec Ruins National Monument, New Mexico. NPS photo taken by Katie KellerLynn

Geologic Mapping for Aztec Ruins National Monument

During the scoping meeting, Tim Connors (GRD) showed some of the main features of the GRE Program's digital geologic maps, which reproduce all aspects of paper maps, including notes, legend, and cross sections, with the added benefit of being GIS compatible. The NPS GRE Geology–GIS Geodatabase Data Model incorporates the standards of digital map creation set for the GRE Program. Staff members digitize maps or convert digital data to the GRE digital geologic map model using ESRI ArcGIS software. Final digital geologic map products include data in geodatabase, shapefile, and coverage format, layer files, FGDC-compliant metadata, and a Windows HelpFile that captures ancillary map data. Completed digital maps are available from the NPS Data Store at http://science.nature.nps.gov/nrdata/.

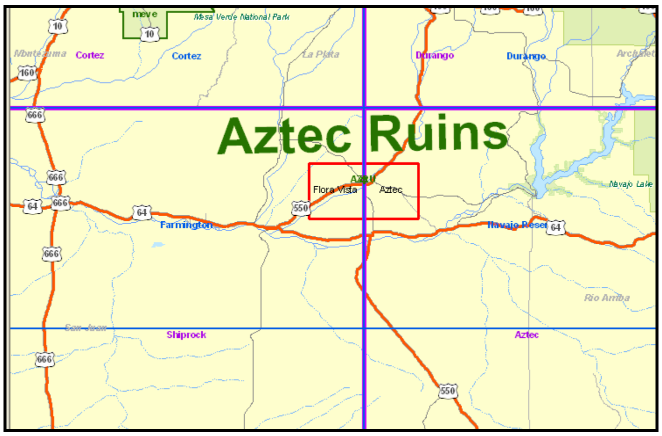

Figure 3. Maps of Interest for Aztec Ruins National Monument. The national monument has two "quadrangles of interest": Aztec and Flora Vista. The figure shows USGS 7.5' quadrangles (red outline; black labels), 30' × 60' sheet (blue outline and labels), and 1° × 2° sheets (purple outline and labels).

When possible, the GRE Program provides large scale (1:24,000) digital geologic maps for each park's area of interest, which is often composed of the 7.5-minute quadrangles that contain park lands (fig. 3). Maps of this scale (and larger) are useful for resource management because they capture most geologic features of interest and are accurate within 40 feet (12 m). The process of selecting the appropriate maps begins with the identification of existing geologic maps in the vicinity of the park. Scoping session participants then select suitable source maps for digitization by GRE staff. If new mapping is needed, participants discuss necessary resources, timelines, aerial extent of new mapping, and suitable scale, as well as propose who (agency or person) can best produce the map. Table 2 lists the source maps chosen for Aztec Ruins National Monument (AZRU). Each map has been given a unique "GMAP ID" used for data management purposes. These numbers appear in table 2 and with map citations in this summary.

Aztec Ruins National Monument is situated on two 7.5-minute quadrangles: Aztec and Flora Vista (figs. 3 and 4). The known geologic map coverage for both of these quadrangles includes bedrock geology, surficial geology, coal potential, and geomorphic terraces; this information is available at adequate scales for resource management. None of the selected maps is known to exist in a digital-GIS format, so GRE staff will digitize the source maps and create a geodatabase from them (see table 2).

To provide digital geology for the Aztec 7.5' quadrangle, GRE staff will use the following sources:

- **Bedrock and surficial geology**: (73376) Brown, D.R., and Stone, W.J., 1979, Geologic map of Aztec 15' quadrangle, San Juan County, New Mexico (hydrogeologic sheet 1, figure 3), *in* Hydrogeology of Aztec 15' quadrangle, San Juan County, New Mexico: Socorro, New Mexico, New Mexico Bureau of Mines & Mineral Resources, New Mexico Institute of Mining and Technology, scale 1:62,500.

- **Coal:** (41613) Dames and Moore, 1979, Coal resource occurrence and coal development potential maps of the southwest quarter of the Aztec 15' quadrangle, San Juan County, New Mexico: U.S. Geological Survey Open-File Report OF-79-1117, scale 1:24,000, http://pubs.er.usgs.gov/usgspubs/ofr/ofr791117 (see fig. 5).

- **Terrace deposits:** (74618) Gillam, M.L., 1998, Terraces of the Aztec quadrangle, San Juan County, New Mexico, scale 1:24,000 (see fig. 6); unpublished field mapping *for* Gillam, M.L., 1998, Late Cenozoic geology and soils of the lower Animas River valley, Colorado and New Mexico [Ph.D. dissertation]: Boulder, Colorado, University of Colorado, scale 1:50,000.

To provide digital geology for the Flora Vista 7.5' quadrangle, the following sources will be used:

- **Bedrock and surficial geology:** (115) Ward, A.W., 1990, Geologic map emphasizing the surficial deposits of the Farmington 30' × 60' quadrangle, New Mexico and Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-1978, scale 1:100,000.

- **Coal:** (41612) Dames and Moore, 1979, Coal resource occurrence and coal development potential maps of the Flora Vista quadrangle, San Juan County, New Mexico: U.S. Geological Survey Open-File Report OF-79-1116, scale 1:24,000, http://pubs.er.usgs.gov/usgspubs/ofr/ofr791116 (see fig. 5).

- **Terrace deposits:** (74619) Gillam, M.L., 1998, Terraces of the Flora Vista quadrangle, San Juan County, New Mexico, scale 1:24,000 (see fig. 6); unpublished field mapping *for* Gillam, M.L., 1998, Late Cenozoic geology and soils of the lower Animas River Valley, Colorado and New Mexico [Ph.D. dissertation]: Boulder, Colorado, University of Colorado, scale 1:50,000.

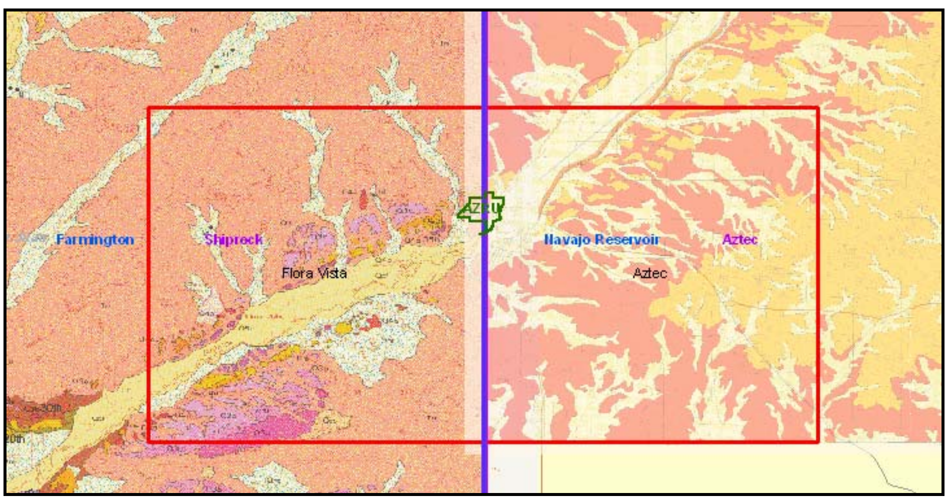

Figure 4. Aztec 15' and Farmington 30' × 60' Geologic Maps. The footprint of both maps is shown in relation to the monument's boundary and quadrangles of interest. The boundary is the green outline at the center of the figure. The figure shows USGS 7.5' quadrangles (red outline; black labels), 30' × 60' sheet (blue outline and labels), and 1° × 2° sheets (purple outline and labels).

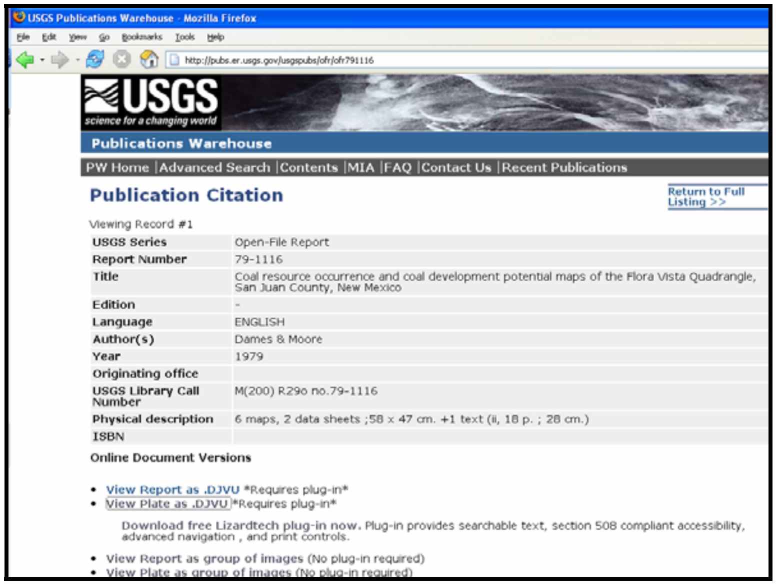

Figure 5. Screen Capture of USGS Web Site of Coal Maps. GMAP 41613 and 41612 (Dames and Moore, 1979) are available digitally, but the supplied Web sites deliver them in a compressed format called “DjVu” by LizardTech. This format is non-GIS based and to view them, users must first download a browser plug-in from http://www.lizardtech.com/download/dl_download.php?detail=doc_djvu_plugin&platform=win.

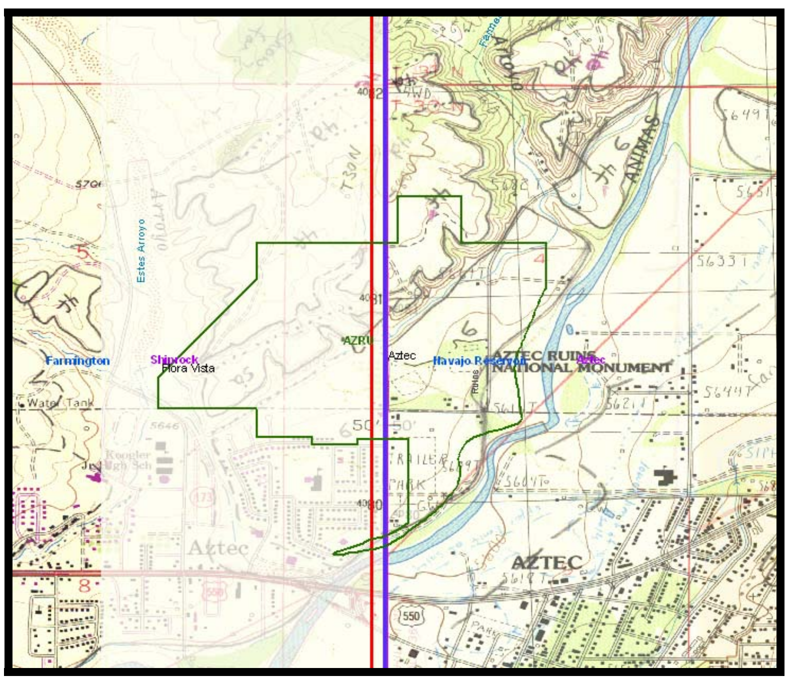

Figure 6. Terrace “Geomorphic” Map around Aztec Ruins National Monument. The monument boundary is the green outline. The figure shows USGS 7.5' quadrangles (red outline, black labels), 30' × 60' sheet (blue outline and labels), and 1° × 2° sheets (purple outline and labels). *Source*: Gillam (1998).

Geologic Resource Management Issues

The scoping session for Aztec Ruins National Monument provided the opportunity to develop a list of geologic features and processes, which will be further explained in the final GRE report. As reflected by O'Dell (2001) and comments from park staff during scoping, oil and gas development is a principal concern at Aztec Ruins National Monument. This issue is listed first, followed in alphabetical order by other issues related to the geology of the monument.

Oil and Gas Development

New Mexico has some of the most significant energy reserves in the lower 48 states and has been and will continue to be a major player in the energy future of the United States (Brister and Price, 2002). In particular, the northwestern portion of the state, known as the San Juan Basin, has played a vital role in the energy business and overall economy of New Mexico (Brister and Price, 2002). Aztec Ruins National Monument lies within the San Juan Basin and along the edge of the Mesa Verde–Blanco oil field. At least two dozen active or abandoned gas wells are within ½ mile (0.8 km) of Aztec Ruins. Three gas wells are active in Aztec Ruins National Monument: Bobbie Herrera No. 1 well, Fee 4-A well, and Fee 9Y well. These wells were drilled through multiple producing zones (e.g., Fruitland and Pictured Cliffs formations) and will likely produce gas for 50 years or more. Scoping participants visited the Fee 4-A well during their field trip. XTO Energy operates the Fee 4-A and the Fee 9Y wells in the monument. Manana Gas, Inc., operates the Bobbie Herrera No. 1 well. In addition, the monument contains two active gathering pipelines, maintained by Enterprise Products, and two abandoned wells: Rhods Abram No. 1 and Moya-Hubbard No. 1. These abandoned wells were plugged in 1970 and 1977 respectively.

Private interests have retained the mineral rights on all but the original 27 acres (11 ha) of the monument. Private mineral ownership and a possibility that undeveloped oil and gas resources occur beneath the monument create the potential for additional drilling inside Aztec Ruins National Monument. However, additional wells would be subject to applicable legal and policy requirements, including the NPS nonfederal oil and gas rights regulations in 36 CFR Part 9, Subpart B (9B regulations). The regulations require oil and gas operators in National Park System units to submit a plan of operations for NPS approval. The plan details all activities of the oil and gas development, describes how reclamation will be completed, and provides the basis for performance bonds. The National Park Service uses the information to determine the effects of the proposed operations and alternatives on the environment, park management, and visitor values. Once approved, the plan serves as the operator's permit.

According to O'Dell (2001), existing well operations account for localized and relatively minor impacts to natural resources; vegetation and soils appear to be the most impacted natural resources. Past disturbance associated with the wells and gathering lines on the recently acquired Hubbard property have adversely affected cultural resources. Provided that operations are properly maintained and eventually reclaimed, the threat of additional damage to natural and cultural resources is minor.

Park staff is working with operators to reduce the impacts of present operations on park resources and values. Increased activity such as new drilling, reworking old wells, or replacing gas pipelines has the potential to unnecessarily damage park resources if not properly constructed, maintained, and operated. New well drilling and production operations would be subject to the protective standards of the NPS oil and gas 9B regulations, which require an operator to prevent or minimize damage to park resources and values. Resource protection issues related to the gas gathering system in the park would be addressed through the NPS special use permit regulations at 36 CFR § § 1.6, 5.3, and 5.7 (O'Dell, 2001; Julia Brunner, GRD, personal communication with Lisa Norby, March 22, 2007).

Drilling outside the national monument is occurring and is likely to continue in the future. Potential impacts on cultural and natural resources from drilling and production activities adjacent to the monument would likely consist of visual and sound intrusions on the cultural landscape and visitor experience. The National Park Service would work closely with representatives of the oil and gas industry to help insure that any future drilling and resource extraction surrounding the monument would be done in concert with NPS management goals and objectives and minimize impacts on park resources and the visitor experience. In the event that damage is caused to park resources from activities outside park boundaries, the National Park Service has authority to recover up to treble damages from the company under the Park System Resources Protection Act, 16 U.S.C. §19jj. This strict liability statute authorizes the National Park Service to recover response costs and damages from a person who destroys, causes the loss of, or injures National Park System resources (Aztec Ruins National Monument, general management plan, March 23, 2005).

Development

Aztec Ruins National Monument is located in the City of Aztec. Perhaps one of the most threatened resources at and surrounding Aztec Ruins National Monument is open space. Development and construction immediately adjacent to the monument have destroyed archaeological features and their geologic contexts by bulldozing (Dave Love, e-mail communication, April 24, 2007). Hence, current and future housing development at the edges of the monument could adversely impact park resources and visitor experience. As seen on air photos provided by Rich Friedman (City of Farmington), the Mesa Escondido subdivision north of the monument is a major management concern (see "Hillslope Processes" section).

As development takes place around the monument, developers will likely look upon the open space of the monument as areas to use for urban functions such as new road corridors, new pipeline corridors, and new sports areas for local schools. Such inroads have already occurred at Petroglyphs National Monument in Albuquerque, where the city has extended a major four-lane thoroughfare through the park, moving petroglyphs in the process, to expand access to the city by yet-to-be developed suburban tracts. Alternative routes were deliberately blocked by developers. Access-related vandalism at this park is horrendous (Dave Love, e-mail communication, April 24, 2007).

Disturbed Lands

More than 315,000 acres (127,480 ha) in 195 National Park System units have been disturbed by modern human activities. Some of these features may be of historical significance, but most are not in keeping with the mandates of the National Park Service. Disturbed lands are those park lands where the natural conditions and processes have been directly impacted by development (e.g., facilities, roads, dams, abandoned campgrounds, and user trails), agricultural practices (e.g., farming, grazing, timber harvest, and abandoned irrigation ditches), overuse, or inappropriate use. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, hurricanes, tornadoes, and fires are not considered for restoration unless influenced by human activities.

Restoration activities return the quality and quantity of an area, watershed, or landscape to some previous condition, often some desirable historic baseline. Restoration at disturbed areas directly treats the disturbance to accelerate site recovery and should aim to permanently resolve the disturbance and its effects. For more information about disturbed lands restoration, contact Dave Steensen (GRD, Restoration Program lead) at dave_steensen@nps.gov or 303-969-2014.

Participants of GRE scoping identified a number of disturbed lands at Aztec Ruins. Human activities have modified, impacted, or affected nearly every square foot of the national monument, from ancestral Puebloan through historic time and into the present. These activities include grazing, crop production, irrigation, orchards and their care, habitation, ceremonial use, tourist businesses, park operations, raising livestock, hunting and fishing, archaeological exploration and mitigation, road and fence building, and installation of utilities.

Eolian Features and Processes

Modern eolian processes (e.g., wind erosion of the ruins) are not a management concern. However, deposits of Quaternary loess (windblown dust) occur within the monument. These deposits, which may be as thick as 3 feet (0.9 m), have cultural significance: ancestral Puebloans dug subsurface structures into the loess and made mortar from it (Paul Carrara, U.S. Geological Survey, personal communication, March 8, 2007). The clay content of the loess retains moisture, which was significant for prehistoric farming in the region.

The U.S. Geological Survey is in its second year of a five-year project of mapping the surficial geology, including loess deposits, at Mesa Verde National Park (see http://esp.cr.usgs.gov/info/meve/, accessed March 8, 2007). Information about loess at Mesa Verde may be applicable to Aztec Ruins National Monument. Paul Carrara is the principal investigator of this study (pcarrara@usgs.gov, 303-236-1287). In addition, Doug Ramsey (Natural Resources Conservation Service [NRCS]), who completed the soil survey for Mesa Verde National Park, may be another contact regarding this resource (douglas.ramsey@co.usda.gov, 970-259-3287).

Fluvial Features and Processes

Aztec Ruins is situated along the banks of the Animas River and was used by ancestral Puebloans. Today, people come to recreate on the river (e.g., kayaking, fishing, and canoeing). Because no park infrastructure occurs within the floodplain (Kim Johnson, NPS Water Resources Division, memorandum to AZRU superintendent, May 6, 2004), management concern about flooding of the Animas River is minimal. Also, no arroyo cutting occurs within the monument. During scoping, park staff identified erosion of an archaeological site along the banks of the Animas River as a management concern. This particular site, which participants visited during scoping, is mostly protected from erosion by rip-rap, consisting of cement slabs (fig. 7). The site is part of the "Fallon property," which has had a history of stream erosion and bank failure; for example, a cutbank failed in 1950. This property is within the congressionally approved boundary of the monument. However, the National Park Service had not yet purchased the land from the owner; political and economic circumstances are not currently conducive to acquiring new lands for the National Park System (Gary Brown, AZRU, e-mail communication, March 12, 2007).

Figure 7. Rip-rap Protecting Archeological Site along the Animas River. NPS photo/Kim Johnson

Groundwater

Scoping participants suggested that the irrigation ditch that runs through the monument ("Farmers Ditch" constructed in 1890s) has impacted natural hydrologic flow and may be artificially raising groundwater levels around the ruins.

Since May 2005, the Colorado Plateau Cooperative Ecosystem Studies Unit (CESU) has been conducting a study of the hydrology of Aztec Ruins National Monument in an effort to create a mitigation plan for protecting archaeological sites. The CESU project is in its second and final year; results will be submitted to the National Park Service in summer 2007. The project has focused on identifying the sources of water impacting the major ruins at the monument and designing mitigation measures that, when implemented, will provide protection of the ruins from further deterioration (Filippone et al., 2007).

Hillslope Features and Processes
The ruins were built on alluvial fans that cover the gravelly terrace deposits. Therefore, hillslope processes have been part of the geologic story at Aztec Ruins National Monument. At present, these processes are having minimal effects on park resources. However, the development of the Mesa Escondido subdivision north of the monument may change the timing and duration of rainfall runoff events. Typically runoff from roads concentrates water in drainages faster than what occurs naturally, thereby increasing peak discharge within channels. Greater discharge equates to greater erosive power, which could affect downstream park resources. Also, irrigation (of lawns) in the subdivision may result in unnaturally high groundwater elevations, which could contribute to future landslides onto monument property.

During the field trip, participants discussed the slumping or subsidence of the soils in areas near the East Ruin. The cause of these small depressions or holes is not readily apparent. Some participants suggested that discontinuing irrigation of the fields north of the core ruins area when that land was acquired in 2000 may have affected the groundwater levels in this downslope area, contributing to instability and collapse in places.

Mineral Resources and Mining
During GRE scoping, park staff expressed an interest in identifying the sources of many geologic materials found in the national monument (e.g., limestone disks in the kivas) for interpretive purposes. For example, obsidian, probably from the Jemez Mountains, was traded throughout the Southwest and is found in the monument. Additionally, chert from Narbona Pass in the Chuska Mountains southwest of the monument is also found here. Gold occurs in the upper reaches of the Animas River.

Though not significant, some uranium prospecting has occurred in the vicinity of the monument. Many mineral claims pre-date establishment of the national monument. No sand or gravel mining has occurred within the monument's boundaries.

Paleontological Resources
The National Park Service has not conducted an inventory of paleontological resources at Aztec Ruins. A single bedrock outcrop of the Nacimiento Formation occurs in the monument. This formation is known to have vertebrate fossils and petrified wood at other locales. With so few rock outcrops in the monument, however, the likelihood of in situ vertebrate fossils being discovered at Aztec Ruins is slim. Pieces of petrified wood may be found in terrace gravels, however.

Piping
According to the USGS "Water Basins Glossary" at http://capp.water.usgs.gov/GIP/h2o_gloss/, piping is "erosion by percolating water in a layer of subsoil, resulting in caving and in the formation of narrow conduits, tunnels, or 'pipes' through which soluble or granular soil material is removed." Piping is a major management issue in anthropogenic areas such as earthen dams and raised roads (Pete Biggam, NPS soil scientist, e-mail communication, February 23, 2007). Piping can also occur in natural settings, typically when sheetwash erosion starts to concentrate into rill erosion, entering a soil through cracks, animal burrows, fence-post holes, or excavations, and eventually moving through the subsurface to an exit point (Pete Biggam, NPS soil scientist, e-mail communication, February 23, 2007).

Participants identified piping as a minor geohazard at Aztec Ruins National Monument. A memorandum from Kim Johnson (NPS Water Resources Division, Water Operations Branch, May 6, 2004) to the superintendent at Aztec Ruins National Monument identifies irrigation waters as a source of piping along the Animas River floodplain. A pasture above an eroding bank is flood irrigated during the summer months, and irrigation water is allowed to slowly soak into the soil. This excess water in the soil may lead to soil piping (fig. 8). Additionally, piping could affect the stability of archaeological sites via subsidence. Pipes may also have cultural importance; that is, ancestral Puebloans may have "enhanced" natural pipes for human use, even to the extent of excavating a kiva into a soil pipe. For more information about soil piping, contact Pete Biggam (NPS Soils Program) at 303-987-6948 or pete_biggam@nps.gov.

Figure 8. Soil Pipe in Eroding Bank along the Animas River, Aztec Ruins National Monument. The red mark on the ruler is at 1 foot. NPS photo/Kim Johnson

Seismicity

The U.S. Geological Survey has classified this area as having a low seismic hazard potential. To find overall probabilities of earthquakes exceeding a given size, go to http://earthquake.usgs.gov/research/hazmaps; users can search this site by zip code. A magnitude 5.5 earthquake shook Dulce, New Mexico, 50 miles (80 km) east of Aztec on January 22, 1966, and caused more than $200,000 in damages to the town and school (Von Hake and Cloud, 1966). The MM intensity in Dulce was VIII. This quake was felt as far away as Farmington and Durango with MM Intensities of I–IV (Von Hake and Cloud, 1966; Hoffman, 1975; Northrop, 1976).

Soils

The Soil Resources Inventory is complete for Aztec Ruins National Monument and is available via the NPS Data Store at http://science.nature.nps.gov/nrdata/datastore.cfm?ID=41598. The completed soils data and map are not part of the digital geologic map. Nevertheless, as soils were briefly discussed during GRE scoping and Pete Biggam is part of the GRD staff, information about the soils inventory is included here. Aztec Ruins was mapped as part of the soil survey of San Juan County, New Mexico, eastern part (NM618). The mapping was done to National Cooperative Soil Survey (NCSS) standards at an Order 2 level, with the base orthophoto imagery at 1:24,000 scale. The NPS Soil Resources Inventory has obtained the data via the USDA Soil Data Mart and has extracted the data that covers the park. Products include a geospatial digital soils map, MS Access database exported from the National Soil Information System (NASIS), and FGDC compliant metadata (Pete Biggam, GRD, written communication, March 26, 2007). For more information about the soil inventory, contact Pete Biggam (NPS Soils Program) at 303-987-6948 or pete_biggam@nps.gov.

Volcanic Features and Processes

Pieces of porphyritic igneous rocks and volcanic tuff in the terraces at Aztec Ruins are evidence of the Animas River passing through a volcanic region. On its route to Aztec, the river flows through the San Juan volcanic field, which was active about 35 to 22 million years ago. The Lava Creek B ash, which Mary Gillam used in dating and correlating the Animas terraces, is in the vicinity of the monument but does not actually occur within its boundaries

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Table 1. Scoping Meeting Participants

Name	Affiliation	Position	Phone	E-Mail
Gary Brown	NPS-AZRU	Chief of Cultural Resources	505-334-6174 x. 35	gary_brown@nps.gov
Dennis Carruth	NPS-AZRU	Superintendent	505-334-6174 x. 22	dennis_carruth@nps.gov
Tim Connors	NPS-GRD	Geologist	303-969-2093	tim_connors@nps.gov
Rich Friedman	City of Farmington	GIS Supervisor	505-599-1218	rfriedman@fmtn.org
Mary Gillam	San Juan College (New Mexico); Fort Lewis College (Colorado)	Geologist	970-259-0966	gillam@rmi.net
George Herring	NPS-AZRU	Interpretive Supervisor	505-334-6174 x. 27	george_herring@nps.gov
Joe Hewitt	BLM	Geologist	505-599-6365	jhewitt@blm.gov
Katie KellerLynn	Colorado State University	Research Associate/Geologist	801-608-7114	katiekellerlynn@msn.com
Dave Love	New Mexico Bureau of Geology & Mineral Resources	Geologist	505-835-5146	dave@gis.nmt.edu
Terry Nichols	NPS-AZRU	Park Ranger	505-334-6174 x. 23	terry_nichols@nps.gov
Lisa Norby	NPS-GRD	Geologist	303-969-2318	lisa_norby@nps.gov
Phil Stoffer	USGS	Geologist	650-329-5028	pstoffer@usgs.gov
Heather Stanton	Colorado State University	Research Associate/Geologist	970-267-2159	heather_stanton@partner.nps.gov

Table 2. Geologic Inventory List of Maps for Aztec Ruins National Monument

GMAP ID	Citation	Appraisal	GRE action required	URL	Scale
41612	Dames and Moore, 1979, Coal resource occurrence and coal development potential maps of the Flora Vista quadrangle, San Juan County, New Mexico: U.S. Geological Survey Open-File Report OF-79-1116, scale 1:24,000.	2007-0301: 15-page report to incorporate; 8 plates. Digitize plate 1 (coal map) and capture graphics from plate 3 (sheets 1 & 2; coal sheet)	Digitization	http://pubs.er.usgs.gov/usgspubs/ofr/ofr791116	24000
41613	Dames and Moore, 1979, Coal resource occurrence and coal development potential maps of the southwest quarter of the Aztec 15' quadrangle, San Juan County, New Mexico: U.S. Geological Survey Open-File Report OF-79-1117, scale 1:24,000.	2007-0301: 19-page report to incorporate; 19 plates. Digitize plate 1 (coal map) and capture graphics from plate 3 (sheets 1 & 2; coal sheet)	Digitization	http://pubs.er.usgs.gov/usgspubs/ofr/ofr791117	24000
74618	Gillam, M.L., 1998, Terraces of the Aztec quadrangle, San Juan County, New Mexico, scale 1:24,000; unpublished field mapping *for* Gillam, M.L., 1998, Late Cenozoic geology and soils of the lower Animas River valley, Colorado and New Mexico [Ph.D. dissertation]: Boulder, Colorado, University of Colorado, scale 1:50,000.	2007-0301: received topo maps with hand-drawn polygons for stream terraces from Mary Gillam; incorporate into AZRU compiled map	Digitization	z:\gis-nps_by_gmap_id\74618_aztec_NM_7.5'_geomorph	24000
74619	Gillam, M.L., 1998, Terraces of the Flora Vista quadrangle, San Juan County, New Mexico, scale 1:24,000; unpublished field mapping *for* Gillam, M.L., 1998, Late Cenozoic geology and soils of the lower Animas River valley, Colorado and New Mexico [Ph.D. dissertation]: Boulder, Colorado, University of Colorado, scale 1:50,000.	2007-0301: received topo maps with hand-drawn polygons for stream terraces from Mary Gillam; incorporate into AZRU compiled map	Digitization	z:\gis-nps_by_gmap_id\74619_flora_vista_NM_7.5'_geomorph	24000
73376	Brown, D.R., and Stone, W.J., 1979, Geologic map of Aztec 15' quadrangle, San Juan County, New Mexico (hydrogeologic sheet 1, figure 3), *in* Hydrogeology of Aztec 15' quadrangle, San Juan County, New Mexico: Socorro, New Mexico, New Mexico Bureau of Mines & Mineral Resources, New Mexico Institute of Mining and Technology, scale 1:62,500.	2007-0301: covers Aztec 7.5' for AZRU and has great ancillary text on the area; done as hydro map but good geology on it; not known to be digital, so digitize and crop to Aztec 7.5' only. Should adequately cover Aztec 7.5' quadrangle of interest (QOI) for GRE bedrock purposes; incorporate all text and figure from the rest of the publication as well	Digitization	z:\gis-nps_by_gmap_id\73376_Aztec_NM	62500
115	Ward, A.W., 1990, Geologic map emphasizing the surficial deposits of the Farmington 30' × 60' quadrangle, New Mexico and Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-1978, scale 1:100,000.	2007-0301: seems to adequately portray both bedrock and surficial geology for the AZRU QOI, Flora Vista 7.5'; not known to be digital, so digitize and crop to Flora Vista 7.5' only and capture other ancillary information	Digitization	http://ngmdb.usgs.gov/Prodesc/proddesc_10056.htm	100000